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COASTAL ENVIRONMENT OF THE BEAUFORT SEA FROM FIELD DATA AND ERTS-1
IMAGERY, SUMMER 1972^{1/}

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16. Abstracts

An extensive field program during the spring and summer in the coastal Beaufort Sea test site has been completed using a wide variety of sensing techniques. Reduction of field data and ERTS-1 image analysis have shown the coastal environment to be complexly influenced by unique processes, most of which involve or are related to sea ice.

Active sedimentologic processes along the Arctic coast are set in motion by the melting, flooding, and eventual overflow of rivers onto the sea ice. It is now apparent that only minor amounts of sediment are transported offshore at this stage; however, scouring of the bottom is significant beneath the strudels (drain holes) which develop in the fast ice canopy in the region of overflow.

Later during the period of maximum melting (late June and July), temperatures and turbidities decrease offshore while salinities increase then decrease as the pack ice is approached offshore. Areal salinity and turbidity patterns together with ERTS-1 imagery confirm a consistent influx of colder, clearer, saltier water towards the coast just east of the Colville River. Strong (up to 3 knots) bi-directional but intermittent currents often manifest themselves in imagery and aerial photographs as wakes behind grounded ice. Ice movement vectors generated from repetitive images indicate that ice drift is closely associated with wind direction, especially in shallow bays, and displacements of 4-22 kilometers were noted in 24 hours.

Nearshore topographic highs serve as loci of grounded ice whose keels are of sufficient depth. Side-scan sonar data confirm that these areas are intensely gouged by ice.

17. Key Words and Document Analysis. (a). Descriptors

- Marine geology
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- Ice scouring
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- Shelf ice
- Turbidity

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TYPE II PROGRESS REPORT

ERTS-1

- a. Title: Studies of the Inner Shelf and Coastal Sedimentation
Environment of the Beaufort Sea from ERTS-1

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Subdisciplines: 3I, 4C, 5B, 5E, 5F, 5G, 5H, 7D.

- b. GSFC ID No. of P.I.: IN 394

- c. Statement and explanation of any problems that are impeding the progress of the investigation.

After several months of receiving randomly dated images, and organizing and examining these images and the catalogs, we question whether we have seen all of the usable imagery of our test site. In most cases our doubt has been raised by 1) a dearth of information in a particular area or 2) gaps in data where data on previous and following days were excellent. Questions: a) how can we be sure ice has not been interpreted as clouds, b) how do we know our 60% cloud cover criterion does not exclude images in which the remaining 0-40% has good data?

Considering the emphatic need for repetitive synoptic data for our study of processes coupled with the generally extensive cloud cover in our test area, we need to use every image that has usable data.

- d. Discussion of the accomplishments during the reporting period and those planned for the next reporting period:

An extensive series of field studies was carried out in the test site area first during the initial overflow of Arctic rivers onto the sea ice in May and June. Then, during the open season, extending from the middle of July to the middle of September, studies were continued offshore using three different research vessels. The primary accomplishments of these studies pertaining to the ERTS-1 program have been to obtain data on water characteristics (temperature, salinity, turbidity, particulate matter, currents), ice characteristics (thickness, movement, sediment load), and sediment characteristics (texture, depositional history, movement). Observations on the interrelations and processes involved in creating these characteristics were also obtained.

Since receiving our first ERTS-1 imagery, "first look" analysis is complete for all images of the test site area prior to the space craft shutdown on 1 November owing to low sun angle. Images have been selected 1) that are coincident with and can be correlated with our field data and 2) that demonstrate events and processes within the test area. These are scheduled for further analysis. To date we have been able to extract the following information from the images in conjunction with field data:

- a) distribution of suspended matter, temperature, and salinity along the coast.
- b) coastal current directions from grounded ice and ice distribution patterns.

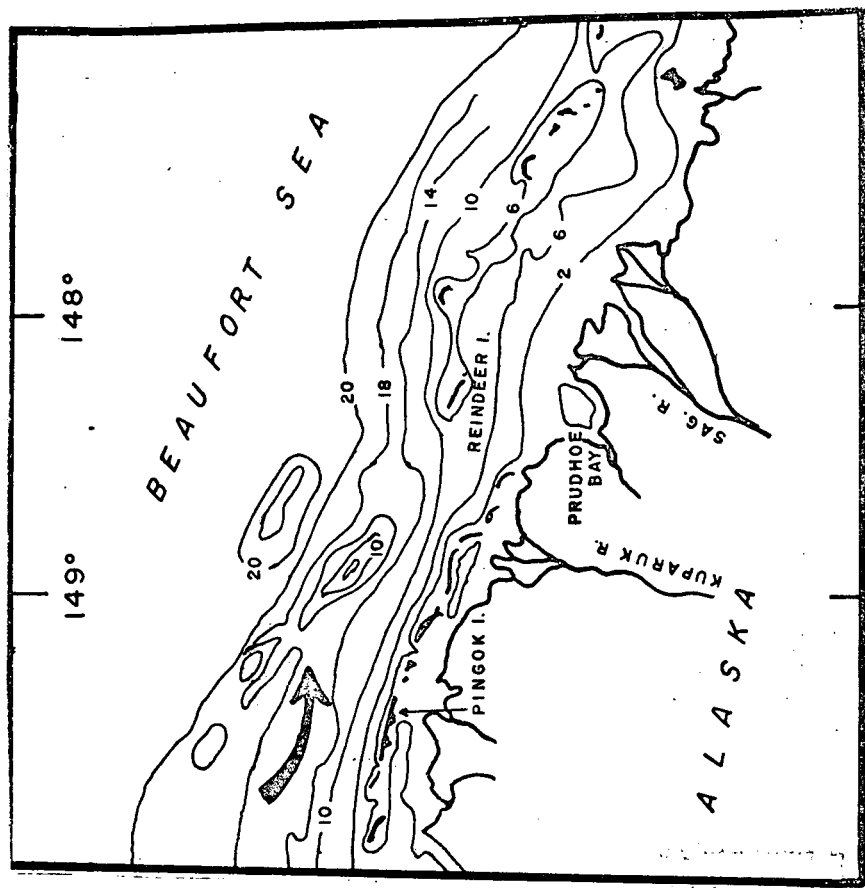


Figure 2. Bathymetry of a part of the shelf off northern Alaska, showing the location of ridges northeast of Pingok Island that apparently serve as loci for ice grounding and coincide with the strip of grounded ice in Figure 3.

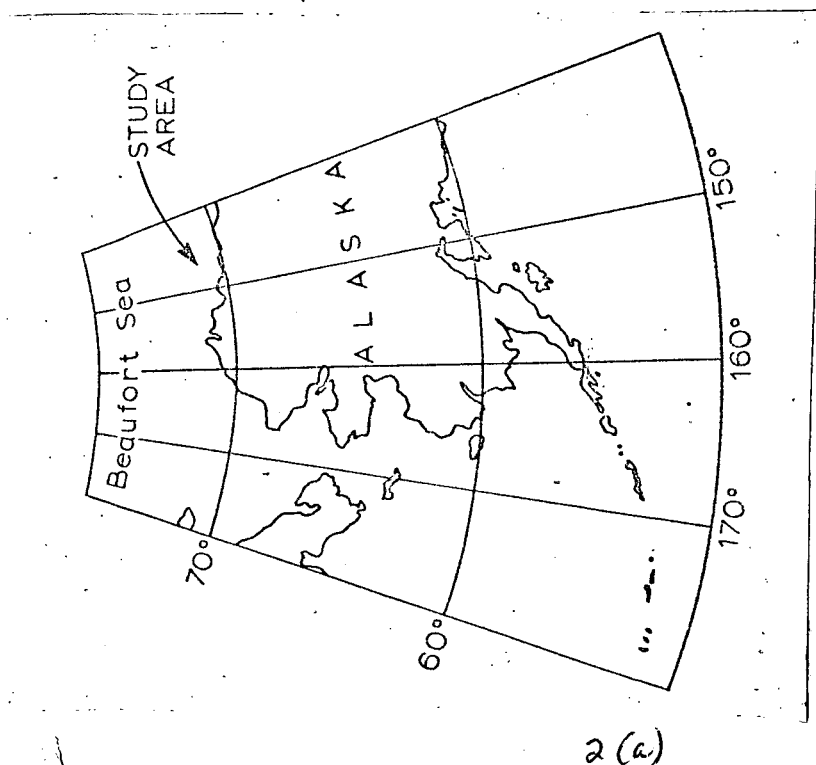


Figure 1. Location of the study area on the northern Alaska coast and continental shelf.

c) measured ice movement patterns from successive, overlapped images.

d) correlation of grounded ice with topographic highs.

Much of our test site field data has been reduced to map form so that it is compatible with, and can be compared to, the ERTS-1 imagery. These include:

- a) Ice gouge patterns on continental shelf from side scan sonar records.
- b) A modified bathymetric map of the entire test site from older charts and our new data.
- c) Temperature, salinity, and turbidity distribution for selected 1, 2, and 3-day periods in July and for longer periods during the open seasons of 1971 and 1972.
- d) Distribution of suspended particulate matter in surface waters prior to and during the open season for 1971 and 1972.

Present plans call for polishing these data reductions and correlating with ERTS-1 images. Considerable emphasis will now be placed on preparing papers for publication, until receipt of 1973 ERTS-1 images.

- e. Discussion of significant scientific results and their relation to practical applications or operational problems including estimates of the cost benefits of any significant results.

Significant results from ERTS-1 investigations on the North Coast of Alaska (Fig. 1) have been achieved in five areas. These findings, along with potential applications, if any, are best presented separately.

- 1) Along many Arctic coasts, rivers flow prior to the melting and breakup of sea ice; the initial flow of the Kuparuk River in northern

Alaska during the spring of 1972 inundated the lagoonal ice behind a chain of islands. Non-turbid water advanced along a lobate front at 15 to 25 cm/sec, first inundating the ice inside and finally outside the lagoons to an average depth of 1 m. The advancing sheet of fresh water reached its maximum extent within 72 hours and carried very little sediment and virtually no river ice, sand, or gravel. Beyond the 2-m contour where ice is not supported by the sea bottom, major cracks developed from the weight of the overflow waters. Along these cracks and at seal holes and fractures seaward, the overflow water drained, forming strudels and allowing the ice to return to equilibrium state. The scour depressions that developed below the strudels were up to 10 m in diameter and 4 m deep, profoundly disrupting the bottom sediments.

2). It has long been known that ice in many forms interacts with the sea floor in Arctic coastal regions. Bathymetric, side-scan sonar, high-resolution sediment profile records, and observations from SCUBA dives, coupled with imagery, show ice to be an important geologic agent on the Beaufort Sea shelf of Alaska. An elongate topographic high with a crest at a water depth of 8-15 m extends for about 25 miles west of Reindeer Island (Fig. 2). The seaward flank of this ridge is extensively marred with grooves up to 1.5 m deep, whereas the landward slope is virtually free of these features. Observations made during SCUBA dives reveal the grooves to be sediments plowed up into unstable ridges. Similar relations were found on other ridges and seaward slopes of the offshore islands. Imagery

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Figure 3. Belt of apparently grounded ice north of Pingok Island, which coincides with a submarine ridge. This ridge is extensively scoured by fragment ice contact (ERTS-1 image on 12 August 1972 1020-21281-5). (See Fig. 2 also.)

4 (a)

from August 12, 1972, shows the ridge west of Reindeer ~~is the locus~~ of a mass of grounded ice (Fig. 3). The initial congruity of the gouged bottom and grounded ice mass confirms the source of the grooves as grounding ice that is presently active in scouring the bottom.

The practical implications of these observations are twofold: first, the safety of offshore platforms, structures, and pipelines depends on the rate, depth, distribution, and intensity of ice gouging, and second, shipping will be guided by the presence or absence of barriers to onshore movement of ice.

3) The coastal circulation along the Arctic coast of Alaska is poorly understood. Interpretation of conditions here are complicated by the 9-month ice cover, relatively large meteorological tides, and the absence of synoptic data.

The surficial water masses identified during the summer reflect three major sources. The earliest to manifest itself (late June through July) is the low-salinity (0-10 ppm), relatively warm (1-11°C), turbid (<25% transmissivity) river runoff. Early in the season, river water fills the zone between the coast and the yet unmelted, seasonal ice sheet.

As melting progresses (middle of July to August), a second water type develops, related to melt-water contribution by pack ice. These waters are of moderate salinity (5-15‰), low temperature (0-2°C), and high light transmissivity (>70%). The first two surface-water types are generally 1-2 m thick and probably never more than about 5 m in some of the deeper lagoons.

A third water type oceanic water is seen as an overall influence on coastal circulation. This type is characterized by moderate salinity (25-30 ‰), low temperature ($< 1^{\circ}\text{C}$), and relative clarity ($> 60\%$ light transmissivity), and it interacts with the river and ice melt waters to create intermediate types.

Using field measurements of the period from July 27 to 30, 1972 and ERTS-I images from July 25 covering the same region, these three water types could be distinguished readily and successfully correlated. The circulation patterns seen in the imagery correlate most readily with the turbidity and salinity measurements (Figs. 4, 5, and 6). In general, turbidity decreases offshore as the distances to sources of suspended matter (rivers and coastal erosion) increase. Salinity increases initially in an offshore direction then decreases as the offshore pack is approached. Usually the turbidity gradient is obvious in the spacecraft imagery. The observed offshore decrease in salinity correlates well with the location of the pack ice and its melt waters.

Perhaps one of the most interesting features noted in this image and confirmed by field data is an area of clearer, more saline water close inshore just east of the Colville River. Upon examining temperature and salinity data available for the entire 1972 summer season and the summer seasons of 1970 and 1971 in the same area, a similar pattern of colder, saltier water east of the Colville was found. Apparently, this influx of oceanic water is a

- Figure 4. Salinity of surface waters in parts per thousand, mainly from values taken from July 27 - 31, 1972. Interpretation and contouring was aided by data obtained in August and September of 1970, 1971, and 1972. Note the high-salinity water near Oliktok Point. (See also Figures 3 and 5.)
- Figure 5. Water turbidity as percent transmission of light (transmissivity). From field data obtained between July 27 - 31, 1972. The interpretation and contouring were aided by 1971 data and ERTS-I imagery of July 25, 1972. (See Fig. 3.) Note the relatively clearer water west of Oliktok Point and the similarity of this figure to Figure 4.

SURFACE WATER SALINITIES
IN PARTS PER THOUSAND-‰

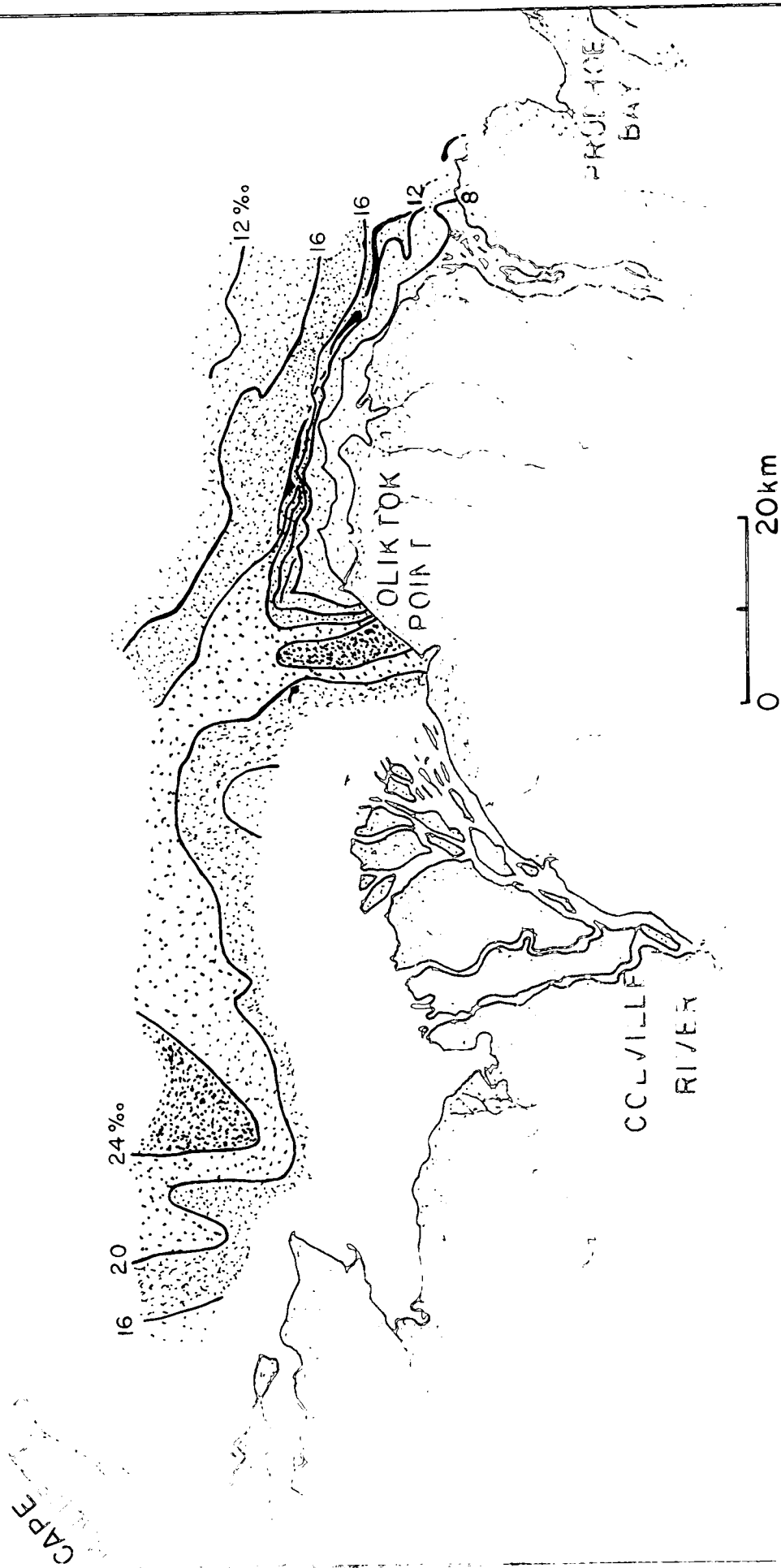


Figure 4

SURFACE WATER CLARITY
AS % TRANSMISSIVITY

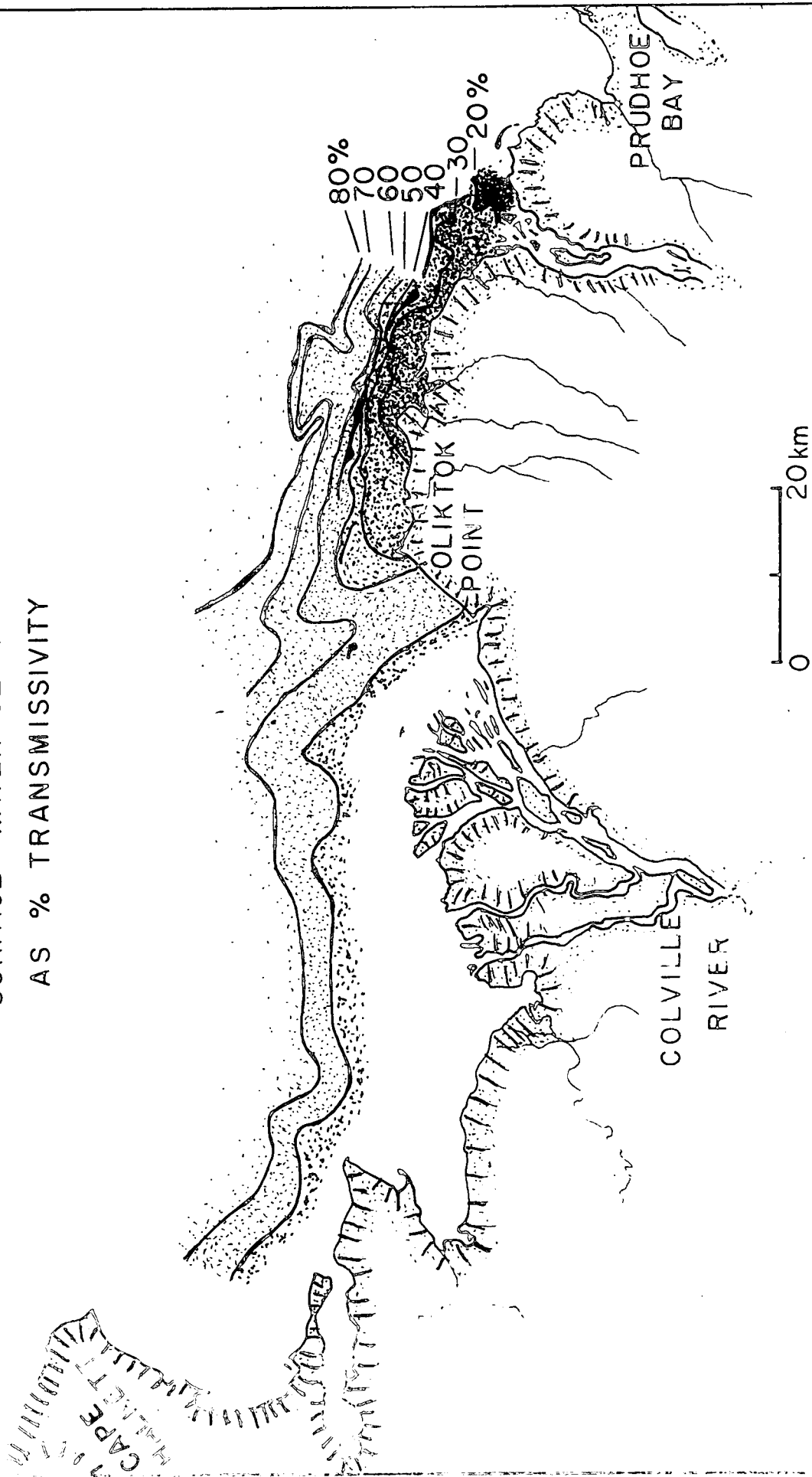


Figure 5

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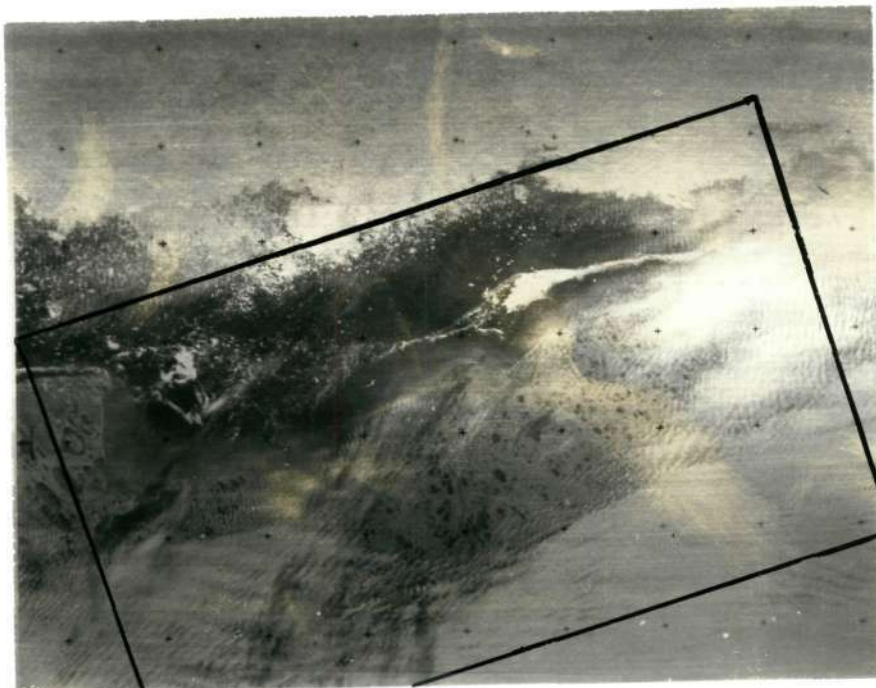


Figure 6. ERTS-I image (RBV) of July 25 covering area of field data (Figs. 4 and 5). A turbid water mass can be seen close in along the coast and off the delta of the Colville River. The large accumulation of ice fragments blocked up against the offshore islands NE of the Colville delta is "streaming" bits of ice to the west. Note the intrusion of clearer water near the coast just east of the Colville delta (from ERTS-I image 1002-21300-3).

fairly permanent feature. This region represents either an area of upwelling under the influence of the dominant northeast winds or clockwise circulation in Harrison Bay and an entrainment of offshore water. In any event, it strongly suggests that Colville River detritus is carried mainly westward towards Cape Halkett.

4) Currents are another aspect of coastal circulation for which data are scant. Field data show considerable variability in current speed and direction, which seem related to wind stresses. Under the influence of dominant northeasterly winds, currents flow to the west, whereas during most stormy periods when westerly winds prevail, currents along the coast flow to the east. Velocities over 2 knots (100 cm/sec) have been measured.

Careful examination of individual ERTS-I images has aided us in determining water movement in two ways: first, the orientation of wakes behind larger pieces of grounded ice indicates the direction of water flow, and second, grounded and perhaps drifting segments of the pack ice often "stream" smaller pieces in a pattern that can be used to interpret direction of surface currents. Care must be exercised in using this latter technique to ascertain that wind-driven ice drift is not interpreted as currents. Although ice and surface waters generally move in the same direction, the rates and direction of each could vary considerably.

5) Ice movement and distribution in the Beaufort Sea play an important part in any shipping and development along this coast.

It has been known that wind and ice movement directions correlate quite well (Sverdrup, 1928); our summer observations confirm this. A set of overlapping ERTS-I images taken on October 7 and 8, 1972, with demonstrates the same relation but with considerable variance. These images also show that wind stress has separated new bay ice from the coast (Figs. 7 and 8).

In Harrison Bay maximum displacement of new ice was about .5 km/hr in a northeasterly direction. Ice movement 100 km offshore varied from a northwesterly direction at up to .8 km/hr paralleling the coast and the average current (H.O. Office, 1958) to a northeasterly direction at up to .4 km/hr. The corresponding winds during the 24-hour period between images averaged about 17 km/hr from the southwest. It appears that the thin new bay ice more closely parallels wind directions and is affected more by wind than the thick pack ice offshore. Evidently, the pack ice is influenced more by other forces such as currents or intrapack forces.

Figure 7. Ice movement vectors (small arrows) derived from ERTS images from overlapping of passes October 7 and 8. Vector scale is the same as the map scale. The large arrows are average wind directions for October 7 and 8 from ground stations 250 km east and west of this area. The broken arrows in Smith Bay indicate sense of direction of movement as cloud cover precluded vector determination. (See Fig. 6.) Plotted from ERTS-I images 1076- 21392-7 and 21394-7, 1077- 21451-7 and 21453-7.



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Figure 8. Smith Bay and Cape Halkett showing offshore movement of newly formed ice due to southerly and southwesterly wind stresses (ERTS image 1077-21453-7). (See Fig. 7 also.)

8(a)

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Oceanographic atlas of the Polar Seas, Part II, 1958, Arctic: H.O.

Pub. 705, U.S. Navy Hydrographic Office, Washington, D.C.

Sverdrup, H. O., 1928, The wind drifting the ice on the north Siberian

Shelf: Norwegian North Polar Exped. with the Maud 1918-1925,

Sci. Results, v. 4, no. 1, 46 p.

f. A list of published articles, papers, preprints, in-house reports, and abstracts of talks that were released during the reporting period:

Reimnitz, E., Barnes, P. W., Forgatsch, T. C., and Rodeick, C. A.,

1972, Influence of grounding ice on the Arctic shelf of Alaska:

Marine Geology (in press).

Reimnitz, E., 1972, Sea ice as a geological agent affecting the

margin of the Arctic [abs]: Am. Geophys. Union Trans.,

v. 53, no. 11, p. 1008.

Barnes, P. W., 1972, River overflow onto the sea ice off the northern

coast of Alaska, Spring (1972) [abs]: Am. Geophys. Union Trans.,

v. 53, no. 11, p. 1020.

Reimnitz, E., and Barnes, P. W., 1972, Studies of the inner shelf and

coastal sedimentation environment of the Beaufort Sea from

ERTS-A: Natl. Tech. Info. } Service Weekly Abs., E72-10062, 5 p.

Barnes, P. W., and Reimnitz, E., 1972, Studies of the inner shelf

and coastal sedimentation environment of the Beaufort Sea from

ERTS-A: Natl. Tech. Info. } Service Weekly Abs., E72-10248, 6 p.

- g. Recommendation concerning practical changes in operations, additional investigative effort, correlation of effort and results as related to a maximum utilization of the ERTS system:

None except as noted in (c.) above where the loss of data owing to cloud-cover criterion or data gaps may be significant.

- h. A listing by date of any changes in Standing Order Forms:

No changes.

- i. ERTS Image Descriptor forms:

None.

- j. Listing by date of any changed Data Request forms submitted to Goddard Space Flight Center/NDPF during the reporting period:

None.

ADDENDUM

In response to the NASA, GSFC letter of January 31, 1973 regarding the NASA aircraft program in support of ERTS-I:

Our use of NASA aircraft imagery in support of our ERTS-I investigation is virtually nil because of (1) the remoteness of our test site in northern Alaska, (2) the generally poor weather at the test site, and (3) our lack of time and interest in administering a "mini-project" with its requests, logistics, and report writing.

The availability of imagery from larger efforts - generally with aims different than ours and without the above problems --whose NASA aircraft flights have overflowed our test site area has been valuable to our project. In particular, some of the AIDJEX nearshore imagery promises to be useful in our study.

In specific response to the January 31 letter:

1) Is the support provided to the ERTS investigators by the Aircraft Program adequate or too large or too small?

This question is not applicable to this experiment.

2) Are the data products being delivered to investigators in a timely fashion, and what is their quality.

Not applicable.

3) How are the aircraft data being applied in support of the ERTS investigations.?

It is anticipated that NASA imagery taken under the AIDJEX 1972 program along the coast will be of use in determining the location of pack ice-fast ice shear zone when this imagery is received. This zone is believed to have a significant influence on shelf sedimentation.